High-rate Deposited Hydrogenated Microcrystalline Silicon Solar Cells

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ABSTRACT

Hydrogenated microcrystalline silicon (μc-Si) has been shown to possess suitable optoelectronic properties for use as the absorber layer of *p i n* solar cells. The main advantage of using μc-Si over the more commonly used hydrogenated amorphous silicon germanium in multijunction cell is the avoidance of the expensive germane gas. However, issues concerning the deposition rate and open-circuit voltage need to be addressed before μc-Si can become economically viable for photovoltaic applications. This paper describes approaches we propose for improving deposition rates by using very high frequency and microwave excitation in plasma-enhanced chemical vapor deposition. Key techniques such as hydrogen dilution, ion bombardment, control of movement of species in the film growth surfaces, and use of strong etchant gases will be described. Preliminary data will also be given.

1. Introduction

μc-Si solar cells have been extensively studied in the last decade [1]. Recent progress has shown an initial efficiency of over 10% for a single junction μc-Si solar cell [2] and over 14% for an a-Si/μc-Si double-junction solar cell [3]. The advantage of using μc-Si over a-SiGe alloy in a solar cell is the avoidance of the expensive germane gas and better stability. However, several issues need to be investigated before adopting μc-Si solar cells in production. The first issue is the deposition rate. In order to get sufficient absorption of the long wavelength light, a few micrometer thick intrinsic μc-Si layer is required. For a comparable throughput, the deposition rate of μc-Si has to be much higher than that of a-SiGe alloy. μc-Si is normally made with hydrogen dilution, which significantly reduces the deposition rate. Therefore, the increase of deposition rate is very important for μc-Si solar cells. Jones *et al.* has achieved a high rate deposition of μc-Si solar cells with a Gas Jet system, an efficiency of 7.0% was obtained at a deposition rate of 15 Å/s [4]. As the rate was increased to 60 Å/s, the cell performance became poor [5]. The second issue is that the open circuit voltage (V_{oc}) is low for μc-Si solar cells. To obtain a high efficiency double-junction solar cell, a relatively thick a-Si top cell is necessary for the a-Si/μc-Si double-junction structure, which may cause a poor stability.

In our laboratory, we started working on the deposition of μc-Si solar cells in July, 2001. In this paper, we present technical approaches for increasing the deposition rate and show preliminary results on μc-Si solar cells.

2. Experimental Approaches

We have two multichamber systems using RF, VHF and microwave excitations. These systems have been used for the deposition of a-Si and a-SiGe based solar cells at high deposition rates [6,7]. As a first step, we use 75 MHz VHF excitation to deposit μc-Si solar cells at deposition rates around 3-5 Å/s. High pressure has been shown to improve μc-Si quality [5], attributed a reduction of high-energy ion bombardment. However, high pressure may cause polymerization and produce powder in the plasma. Furthermore, it is difficult to obtain uniform deposition over a large area for high pressures. We will use an external bias on the substrate to control the ion bombardment. High hydrogen dilution is essential for μc-Si deposition. It is believed that hydrogen etching helps the growth of μc-Si. Fluorine has a stronger etching effect than hydrogen. We plan to add fluorine-containing gases, such as SiF_4, into the plasma to improve material quality. Other deposition parameters, such as substrate temperature, pressure, and electrode distance will be studied.

To increase the deposition rate further, we will use microwave excitation. We previously demonstrated that a-Si alloys can be deposited at 100 Å/s with reasonable quality [5]. We expect to obtain good quality μc-Si solar cells for deposition rates ~ 20-30 Å/s.

3. Preliminary Results and Discussion

In order to find out the amorphous to microcrystalline transition, we first deposited single junction cells on stainless steel (ss) substrate by varying the SiH_4 to H_2 ratios in the intrinsic layer. The J-V characteristics of the solar cells were measured under an AM1.5 solar simulator at 25 ºC. Figure 1 shows the V_{oc} and FF of the solar cells, with

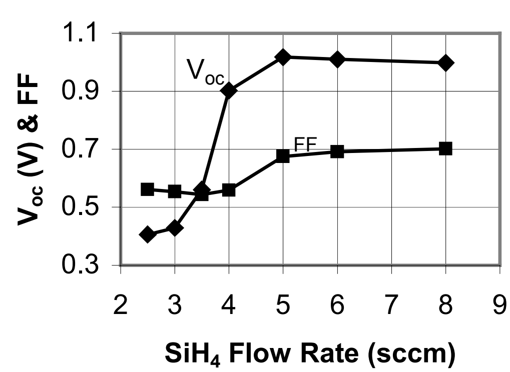

Fig. 1. V_{oc} and FF as a function of SiH_4 flow rate for a fixed H_2 flow rate.

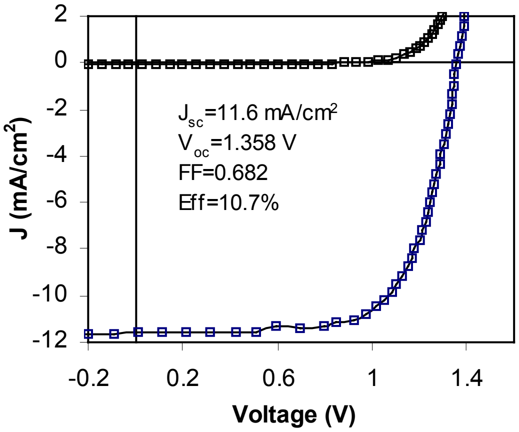

Fig. 2. J-V characteristic of the best a-Si/μc-Si double-junction solar cell.

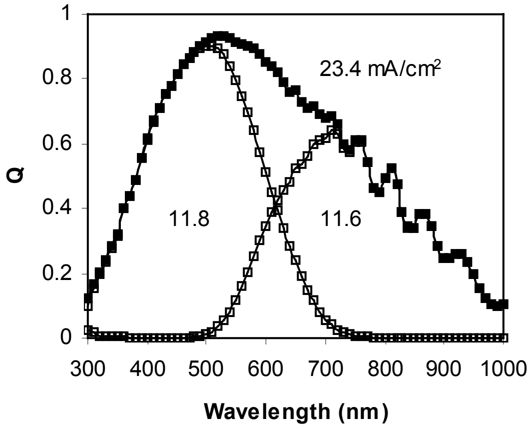

Fig. 3. Quantum efficiency of the double-junction cell shown in Fig.2.

intrinsic layer thickness ~ 2300 Å, as a function of SiH_4 flow rate for a fixed H_2 flow rate. As the SiH_4 flow rate is decreased from 8 to 5 sccm, the V_{oc} increases slightly, but drops dramatically near flow rates ~3-4 sccm, indicating the transition from amorphous to microcrystalline phase. The FF also drops when the dilution ratio approaches the microcrystalline formation regime. The microcrystalline formation depends not only on the hydrogen dilution ratio, but also on the cell thickness. For a thicker cell, one can obtain μc-Si at a lower dilution.

We also deposited μc-Si single-junction and a-Si/μc-Si double-junction solar cells on AgZnO back reflector coated ss substrates. The intrinsic μc-Si layer is ~1.5 μm thick and is deposited at a rate of ~3-5 Å/s. As listed in Table I, the highest 0.25 cm^2 active-area initial efficiencies are 5.6% and 10.7% for a μc-Si single-junction and an a-Si/μc-Si double-junction solar cell, respectively. Figures 2 and 3 show the J-V characteristics and quantum efficiency of the double-junction cell. A significant long wavelength response is a signature of microcrystalline silicon. As can be seen from Fig.3, the double-junction cell is current limited by the bottom cell, continue optimization and stability studies are under way.

4. Conclusion

Technical approaches for making μc-Si solar cells at high deposition rates are discussed. Preliminary results show an initial efficiency of 5.6% for a μc-Si single-junction cell and an efficiency of 10.7% for an a-Si/μc-Si double-junction cell. We just started this project in July, 2001. We expect to improve the cell performance and increase the deposition rate by using approaches mentioned in the paper.

TABLE I. Initial J-V characteristics of μc-Si single-junction and a-Si/μc-Si double-junction cells.

Structure	J_{sc} (mA/cm^2)	V_{oc} (V)	FF	Eff (%)
μc-Si	20.40	0.443	0.609	5.6
a-Si/μc-Si	11.60	1.358	0.682	10.7

5. Acknowledgment

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REFFERENCES

[1] J. Meier, P. Torres, R. Platz, S. Dubail, U. Kroll, J. A. A. Selvan, N. P. Vaucher, Ch. Hof, D. Fischer, H. Keppner, A. Shah, K. –D. Ufert, P. Giannoulès, and J. Koehler. " On the way towards high efficiency thin film silicon solar cells by the 'micromorph' concept," in *Mat. Res. Soc. Symp. Proc.* ***420***, 1996, pp.3-14.

[2] K. Ogawa, K. Saito, M. Sano, and A. Sakai. "Over 10% efficiency solar cell using microcrystalline silicon," in *Technical Digest of International PVSEC-12*, 2001 Jeju, Korea, pp. 343-346.

[3] K. Yamamoto, M. Yoshimi, Y. Tawada, S. Fukuda, T. Sawada, T. Meguro, H. Takata, T. Suezaki, Y. Koi, K. Hayashi, T. Suzuki, and A. Nakajima. " Large area thin film Si module," in *Technical Digest of International PVSEC-12*, 2001 Jeju, Korea, pp. 547-548.

[4] S. J. Jones, R. Crucet, R. Capangpangan, M. Izu, and A. Banerjee. "Assessment of the use of microcrystalline silicon materials grown at rates near 15 Å/s as i layer material for single and multi-junction solar cells," in *Mat. Res. Soc. Symp. Proc.,* 2001, in press.

[5] M. Kondo, T. Nishimoto, M. Takai, S. Suzuki, Y. Nasuno, and A. Matsuda. "High rate growth of amorphous and microcrystalline silicon," in *Technical Digest of International PVSEC-12*, 2001 Jeju, Korea, pp. 41-44.

[6] S. Guha, X. Xu, J. Yang, and A. Banerjee. "High deposition rate amorphous silicon-based multijunction solar cell," Appl. Phys. Lett. **66** (1995) 595-597.

[7] B. Yan, J. Yang, S. Guha, and A. Gallagher. "Analysis of plasma properties and deposition of amorphous silicon alloy solar cells using very high frequency glow discharge," in *Mat. Res. Soc. Symp. Proc.* ***557***, 1999, pp.115-120.